Biomechanical Modeling of the Human Body for Application to Wheelchair Seating Systems

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Background

- Extended periods of sitting in a wheelchair can cause certain postural deformities such as kyphosis or lordosis
- Issues arise due to misalignment of the spine, tilting of the pelvis, or having a poorly positioned center of gravity
- Clinicians implement assistive seating systems into wheelchairs to help adjust a person's body and give them proper posture
- Currently, medical clinicians take measurements of body lengths and ranges of motion of certain body segments
- Issues with these clinical practices include:
  - inaccurate methods for body measurements
  - qualitatively determined ranges of motion of patients
  - clinicians must use prior knowledge of wheelchairs and seating systems to "guess" which would work best and exert the least force on a patient

Purpose

The purpose of this research is to conduct a biomechanical analysis on a human body in a seated position and to analyze the effects of postural supports on the body's alignment in a wheelchair.

Significance

1. Reduce the amount of time clinicians must spend to properly fit a new wheelchair to its user
2. Save wheelchair users money by choosing the correct wheelchair and seating system and by preventing future postural deformities and injuries to the user
3. Enhance the quality of life for wheelchair users

Methods

- Free body diagrams were generated by dividing the body into rigid body segments, where each segment had an approximate length, location, weight, and center of gravity (COG) location
- The data were pulled from the books The Measure of Man and Woman: Human Factors in Design[1] and Biomechanics and Motor Control of Human Movement[2]
- MATLAB was used to determine the COG location of the entire body by using the equation below:

$$X = \frac{1}{M}\sum_{i=1}^{n} m_i x_i$$

$X = location\ of\ COG\ of\ body$

$M = total\ mass\ of\ body$

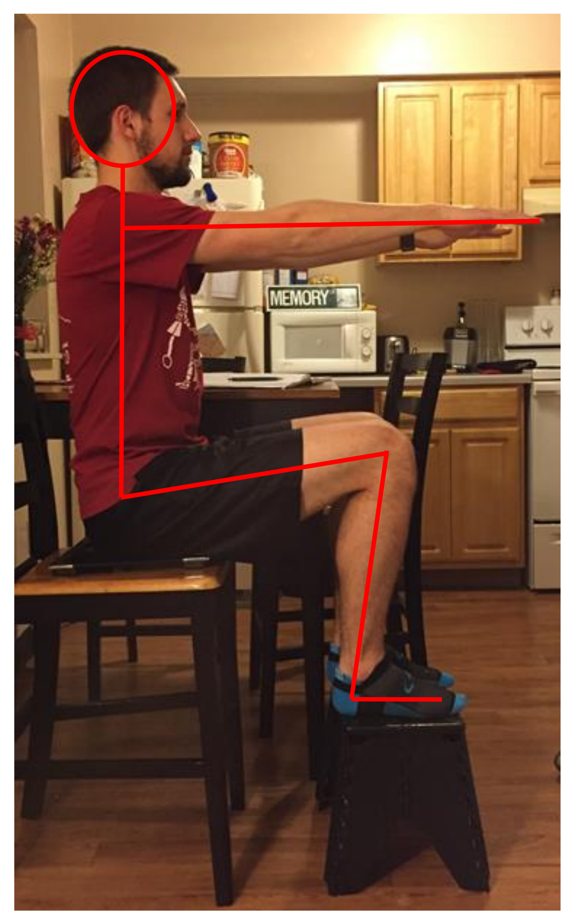
$n = number\ of\ body\ segments$

$m_i = mass\ of\ i^{th}\ body\ segment$

$x_i = location\ of\ COG\ of\ i^{th}\ body\ segment$

Methods (continued)

- The program was written such that specific joint angles (hip angle, knee angle, shoulder angle, etc.) could be inputted into the program to produce a desired posture
- The resultant forces of supports were calculated and outputted to the program's user
- The effect of the location of the arms was determined experimentally by sitting on a scale and reading the outputted weight:



Outputted Weight:
Scale under body = 124.8 lbs
Scale under feet = 45.4 lbs

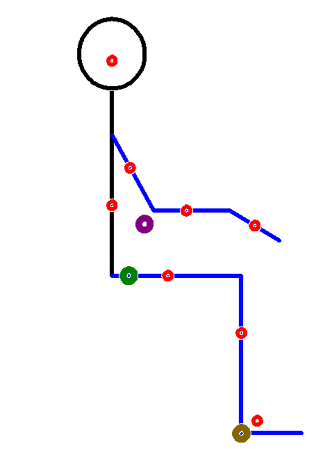
Results

- As the arms moved further away from the body, the scale under the body read less weight while the scale under the feet read more weight
- The MATLAB program found point reaction forces based upon whether or not a body segment was located vertically overtop of a support
- The output of the MATLAB program includes a pictorial representation of the free body diagram and the numerical values for the force associated with each support
- The following models represent a 50th percentile man who has a height of 69.1 inches and a weight of 172 pounds
- The following key identifies what each symbol in the figures represents:

Red Dot = COG of individual body segments
Purple Dot = COG of entire body
Gray Dot = center of pressure of backrest/lateral trunk supports
Green Dot = center of pressure of cushion
Brown Dot = center of pressure of footrest

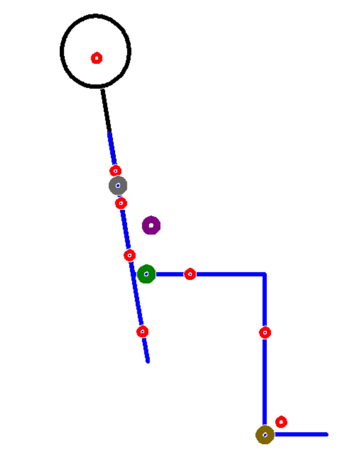
Results (continued)

Seated Upright



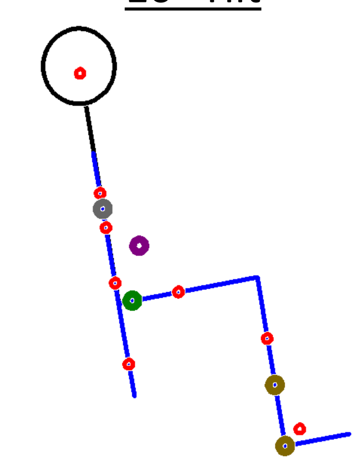
Outputted Forces:
Backrest force = 0 lbs
Cushion normal force = 148.9 lbs
Cushion friction force = 0 lbs
Footrest (behind legs) = 0 lbs
Footrest (under feet) = 23.0 lbs

10° Recline



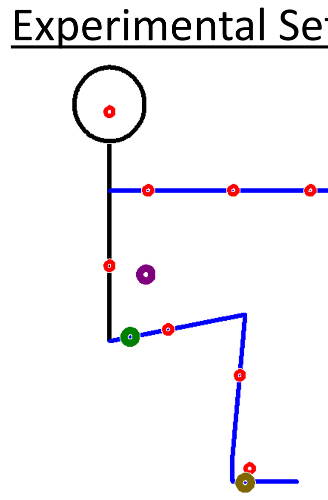
Outputted Forces:
Backrest force = 19.9 lbs
Cushion normal force = 147.6 lbs
Cushion friction force = 19.6 lbs
Footrest (behind legs) = 0 lbs
Footrest (under feet) = 21.0 lbs

10° Tilt



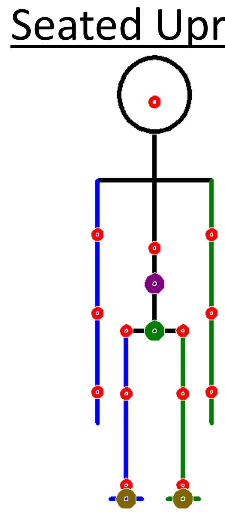
Outputted Forces:
Backrest force = 19.9 lbs
Cushion normal force = 148.7 lbs
Cushion friction force = 6.3 lbs
Footrest (behind legs) = 3.6 lbs
Footrest (under feet) = 20.7 lbs

Experimental Setup



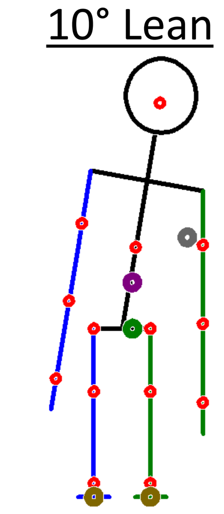
Outputted Forces:
Backrest force = 0 lbs
Cushion normal force = 146.5 lbs
Cushion friction force = 26.8 lbs
Footrest (behind legs) = 0 lbs
Footrest (under feet) = 23.0 lbs

Seated Upright



Outputted Forces:
Left lateral force = 0 lbs
Right lateral force = 0 lbs
Cushion normal force = 152.4 lbs
Cushion friction force = 0 lbs
Left footrest = 9.8 lbs
Right footrest = 9.8 lbs

10° Lean



Outputted Forces:
Left lateral force = 18 lbs
Right lateral force = 0 lbs
Cushion normal force = 149.3 lbs
Cushion friction force = 17.7 lbs
Left footrest = 9.8 lbs
Right footrest = 9.8 lbs

Discussion

- When the wheelchair is in a 10° tilt, the model reads a smaller cushion friction force than when the wheelchair is in a 10° recline
- Sitting with a 10° lean causes a friction force to be produced by the cushion to balance the force from the lateral support
- The difference between the experimental results of sitting on a scale and the theoretical results are due to the localized force of the scale on the body
- Each of the reaction forces of the supports is shown as a point force in order to simplify the governing equations used in the model
- The point forces represent the center of pressure of the respective supports

Some assumptions made in the model include:

1. the footrest has no friction force, but rather acts as two normal forces with one on the back of the shank and one on the bottom of the foot in the side view
2. the feet are always at 90° with respect to the shank, which reduces unknown variables in the equations for the location of the point forces
3. the force from the backrest has no friction component
4. the force from the lateral trunk support has no friction component

Future Work

- Incorporate angles and forces from both views together in order to understand the support's dependence on each other
- Assume a common coefficient of static friction between the person and the support systems to create a relationship between the normal and friction forces
- Utilize OpenSim to determine internal joint torques and muscle activations such that the work can be extended to people with disabilities

Acknowledgements

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References

[1] Tilley, Alvin R. *The Measure of Man and Woman: Human Factors in Design*. New York: Wiley, 1993. Print.

[2] Winter, David A. *Biomechanics and Motor Control of Human Movement*. New York: Wiley, 2009. Print.

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Work Completed at the Assistive Technology Center in the Martha Morehouse Medical Plaza